# CLIVAR

## The Principal Research Areas

# D2: Tropical Atlantic Variability

**Goal:**
**Improving the description and understanding of the patterns of decadal variability originating in the tropical Atlantic.**

## Introduction

Although sea surface temperature anomalies in the tropical Atlantic are weaker than those associated with the Pacific El Niño, they can lead to shifts in climatic patterns over the Americas and Africa that can have major and sometimes disastrous environmental and socio-economic impacts. The well-known drought cycle of North-east Brazil, for example, is closely related to the variability of sea surface temperature (SST) in the tropical Atlantic (Fig. 1).
Of particular importance is a much debated form of variability, seemingly unique to the tropical Atlantic Ocean, that is often referred to as the Atlantic SST dipole. This feature involves a low-frequency oscillation of the SST gradient across the equator, which has spatially coherent SST patterns in the subtropics of either hemisphere. (Fig. 2).
Empirical studies based on 100-year observations suggest that the dipole-like SST variability has a pronounced spectral peak at a period of approximately 12-13 years and accounts for about 20% of the total yearly-averaged SST variance in the tropical Atlantic Ocean (Fig.3).

## Observations

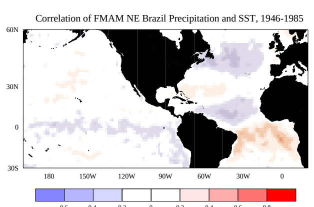



Fig. 1: Correlation between average February through May precipitation in northeast Brazil and sea-surface temperature. Shading indicates regions in which above-normal sea surface temperatures tend to be observed in conjunction with above (below) normal rainfall in Northeast Brazil. The strongest correlations are on the order of 0.5. Northeast Brazil rainfall tends to be more strongly correlated with Atlantic sea surface temperatures than with Pacific sea-surface temperatures. (From "Pan American Climate Studies: A Scientific Prospectus").

### Observed Interannual & Decadal Variability in the Tropical Atlantic

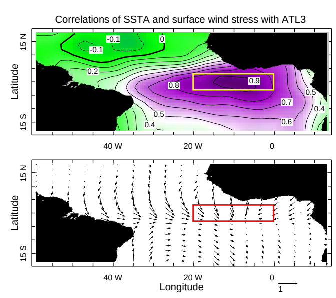



Fig. 2: Upper panel: correlation between the SST anomaly index ATL3 (the area-averaged SSTA in the outlined region) and SST anomalies at all points in the tropical Atlantic basin, based on the Servain et al. (1996, TOGA Atlantic pseudo-stress atlas, 1985-1994, ORSTOM, Brest, 162pp) analyses for the period 1964-1988, according to Zebiak (1993, J. Climate, 2010-2019).
Lower panel: correlation between ATL3 and the zonal and meridional pseudo-stress anomalies (plotted in vector format) based on the same analyses and observation period. (both figures: Zebiak, 1998, Bull. Meteor. Amer. Soc., in press).

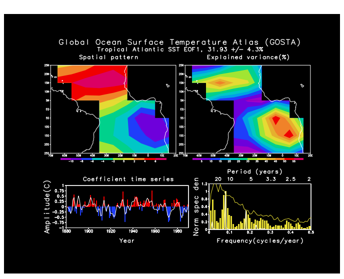



Fig. 3: Empirical Orthogonal Function (EOF) analysis over the domain 30°S - 30°N. Annual-average sea surface temperature anomalies from the GOSTA were used. (a) First EOF multiplied by 10 (contour interval one unit). (b) percent of the total variance "explained" by PC1 in each grid box (contour interval 10%, interval between thick and thin contours 5%), (c) first Principal Component (PC) amplitude (C) time-series, and (d) estimated normalised Fourier spectrum (bars) of the first PC amplitude time-series, the 95% confidence level (light line) for the Fourier spectral peaks obtained with the Monte Carlo technique, and the normalised maximum entropy spectrum (heavy line) of the SSA-filtered PC time-series (Mehta, V., 1998, J. Climate, 11, 2351-2375).

### Cross linkages within other CLIVAR PRA's

This research project is closely related to the following CLIVAR PRA's:

- **D3** Atlantic Thermohaline Circulation
- **D1** The North Atlantic Oscillation
- **G3** Variability of the American Monsoon Systems
- **G4** African Climate Variability

## Programme Objectives

Building upon recent progress towards understanding the underlying dynamics of low frequency variability in the tropical Atlantic, empirical, modelling, and observational research within this area of CLIVAR research will be directed at:

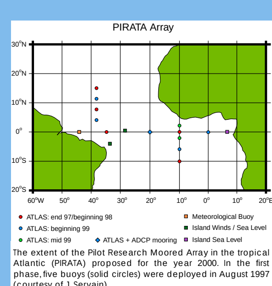
- advancing our understanding of the coupled climate variability in the tropical Atlantic basin and applications toward enhancing a predictive capability for the region;
- seeking to determine whether the two components of the so-called Atlantic dipole are dynamically related, or independent, and what are the physical processes responsible for this variability;
- determining quantitatively how much tropical Atlantic SST variability is attributed to "remote" influences and how much is due to "local" air-sea interactions, e.g. what proportion of low-frequency SST fluctuations in the tropical Atlantic may be influenced by the Pacific, particularly the ENSO-related anomalies; and
- examining the role and predictability of ENSO-like modes of climate variability in the Atlantic, investigating the effect of extra-tropical influences such as the influence of the North-Atlantic Oscillation (NAO) on the tropical Atlantic, and vice versa.

## Sustained observations

The present suite of observations for the tropical Atlantic Ocean consists of

1. a volunteer observing ship (VOS) programme providing surface observations (SST, pseudo wind stress and surface salinity) and subsurface temperature observations (XBTs);
2. coastal and island tide gauge stations which monitor sea level changes in certain regions of the tropical Atlantic Ocean;
3. satellite observations of sea surface temperature, topography, and wind velocity;
4. a small number of drifting buoys which give estimates of SST and surface current velocity.
5. The PIRATA project:

   PIRATA is designed as the Atlantic counterpart of the TAO array in the tropical Pacific. In a three year (1997-2000) pilot project PIRATA aims to provide time-series data of surface fluxes, surface temperature and salinity, and upper ocean heat and salt content to examine processes by which the ocean and atmosphere interact in key regions of the tropical Atlantic. The field phase of PIRATA started with the deployment of two moorings in 1997. Deployment of up to 12 moorings is envisioned as part of a multinational effort involving Brazil, France, and the United States (see box below).




The extent of the Pilot Research Moored Array in the tropical Atlantic (PIRATA) proposed for the year 2000. In the first phase, five buoys (solid circles) were deployed in August 1997 (courtesy of J. Servain).

Deployment of ATLAS buoys during the PIRATA project in autumn 1997 (courtesy of J. Servain).

## Focused Research Projects

The CLIVAR process study projects in the tropical Atlantic Ocean should give the highest priority to the processes that govern SST variability in the off-equatorial regions that have large impacts on rainfall over the Northeast Brazil and Sahel region.

The following are some specific physical processes pertinent to Atlantic dipole variability, and which are also important for a number of principal research areas that ought to be addressed by process experiments in connection with the modelling of atmosphere-ocean interactions:

Air-Sea exchanges processes

Oceanic surface mixed layer processes

Interactions between the ocean surface mixed-layer and thermocline

## Data Set Development

Development of reliable historical data sets is of vital importance not only for empirical studies, but also for model initialisation and verifications. It is thus critical for CLIVAR to support a comprehensive, long-term data set development effort. This effort in the tropical Atlantic should be prioritised according to its ability to improve:

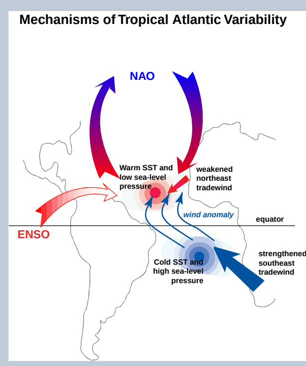
1. our understanding of low-frequency SST variability
2. initialisation and verification of coupled model prediction.

## The Atlantic "Dipole"

**- Two competing theories-**

Two competing hypotheses have been put forward to explain the variability of the cross-equatorial SST gradient.

1.) Decadal variations of the interhemispheric SST gradient stem from regional ocean-atmosphere positive feedbacks involving primarily SST and wind-induced latent heat flux (Chang et al., 1997, Nature, 385, 516-518; Carton et al., 1996, J. Phys. Oceanogr., 26, 1165-1175).
2.) The development of SST anomalies on either side of the equator is dynamically independent and controlled by processes in each hemisphere (Houghton and Tourre, 1992, J. Climate, 5, 765-771; Enfield and Mayer, 1997, J. Geophys. Res., 102, 929-945; Mehta, 1998, J. Climate, 11, 2351-2375).




Different mechanisms explaining the variability of the tropical Atlantic SST and some teleconnections (courtesy P. Chang)

## Modelling

Modelling investigations in CLIVAR will be crucial in addressing scientific questions such as:

- Origins of the interhemispheric SST anomalies
- Importance of different physical processes (air-sea interactions and remote influences)
- Coupled or uncoupled phenomena
- Teleconnections (e.g. with ENSO, NAO)

Different types of models are required to answer these questions.

## Predictability and Prediction

Prediction efforts within CLIVAR should be built upon current successes to further address issues such as:

- Predictability of equatorial Atlantic and interhemispheric SST variability
- Interannual to-decadal prediction of SST in the tropical Atlantic to improve forecasts of African and South American rainfall
- Limits of predictability
- Predictability of the interhemispheric SST anomalies influenced by the equatorial SST variability and the seasonal cycle
- Sensitivity of predictions to initial conditions

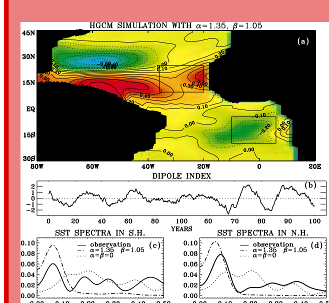



Fig. 4: SST fields simulated by a hybrid coupled general circulation model forced with wind-noise with both dynamic and thermodynamic coupling (a=1.35, b =1.05). The dipole pattern shown in (a) was generated using a regression analysis with a dipole index shown in (b) derived by differencing the model SSTs averaged over a 15°x15° area in each hemisphere indicated by two rectangles. The dipole pattern is insensitive to the choice of the index. The two areas were chosen because of the best availability of the 100-year SST observations in these regions. The 100-year (1890-1990) observed monthly mean SST time-series were derived based on the UK Meteorological Office Main Marine Data Bank by area-averaging over the two regions. The observed SSTs were compared with similar SST time-series derived from model simulations via a spectral analysis. The SST spectra in the Southern and Northern Hemispheres are shown in (c) and (d), where solid lines are for observations, dash-dotted and dotted lines are for simulations with a=1.35, b=1.05 and a=b=0, respectively. The SST spectra were estimated using the Hanning window with a bandwidth M=240 months and were normalised by their own variance. The standard deviations of the observed SST in the Northern and Southern Hemispheres are about 0.5°C. Similar values for the simulated SSTs are about 0.3°C for a=1.35, b=1.05 and are less than 0.1°C for a=b=0 (after Chang et al., 1997, Nature, 385, 516-518).

## Empirical Studies

For the tropical Atlantic climate variability, the empirical analyses based on historical data sets should be focused on issues such as

1. relationships between the northern and southern component of the Atlantic dipole, tropical Atlantic and Pacific SSTs, and tropical and extratropical Atlantic SSTs;
2. relative importance of the tropical Atlantic and Pacific SSTs' influence on rainfall variabilities over America and Africa;
3. linkages between SST, winds and surface heat flux near and off the equator;
4. oceanic and atmospheric processes that control cross-equatorial SST gradient variability;
5. interrelations among Atlantic dipole, equatorial modes and the seasonal cycle;
6. potential links between the SST variability of the dipole mode south of the equator and the changes to the South Atlantic Convergence Zone (SACZ).

## Impacts and Teleconnections

- The variation of the interhemispheric SST gradient has a significant impact on the position and intensity of the Intertropical Convergence Zone (ITCZ), which in turn influence the rainfall over Northeast Brazil (see Fig. 1) and the Sahel in Africa (see Fig. 4). Understanding the predictability of rainfall over these regions has long been a central concern for climate research, because of its extraordinary economic and societal impact. The fact that rainfall variability in these regions is highly correlated with the sea surface temperature anomalies implies that a skilful prediction of the low-frequency SST variability in the tropical Atlantic Ocean may be crucially important for long-term rainfall forecasts around the Atlantic basin.
- In addition to the meridional variability in SST, modelling studies suggest that a mode of variability similar to the Pacific ENSO also exists in the tropical Atlantic Ocean (see Fig. 2). Although it is much weaker than its Pacific counterpart, the Atlantic equatorial mode can have an effect on rainfall in the Gulf of Guinea (Fig. 5). It is possible that this equatorial mode is dynamically related to the off-equatorial SST changes, but no interrelations between these structures have yet been revealed.
- Additionally, strong linkages between the tropical SSTs and the North Atlantic Oscillation (NAO) can be identified (see schematic and Fig. 6).

### Tropical Atlantic SST and West African Rainfall

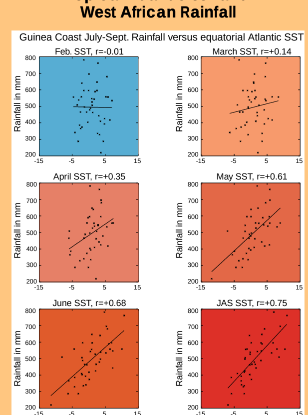



Fig. 5: Scatterplots of Equatorial Atlantic SST anomaly versus July-September seasonal rainfall total in the Guinea Coast region of West Africa. The graphs show the strong association between July-September SST and July-September rainfall, but no association between February SST and July-September rainfall. Therefore, for prediction with a good lead time on the July-September season, there is a need to forecast the Equatorial Atlantic SST (from Ward, M.N., 1998, J. Climate, in press).

### The Basin-wide signal of the NAO

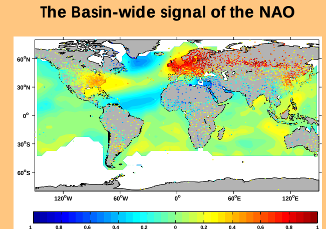



Fig. 6: The correlation between the NAO winter season index as defined by Hurrell (1995, Science, 269, 676-679) and station surface air temperature averaged for the same season (Dec-Mar) (Baker et. al., 1995) and sea surface temperature (1864-1991; using the Kaplan Re-Analysis, (Kaplan, 1998, J. Geophys. Res., in press)). A total of 3086 temperature stations were used, stations with less than 30 years of data were removed. The figure shows the basin-wide extent of the NAO-SST association, with the major association being in the North Atlantic, but also affecting the tropical Atlantic region. (courtesy of Y. Tourre, Y. Kushnir).